Call Admission in Power Controlled CDMA Systems

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Abstract—In power controlled CDMA systems, the number of users that each cell can support is limited by the total interference received at each base station and will vary with time. When a system is congested, admitting a new call can only make the link quality worse for ongoing calls and may result in call dropping. Thus, a system needs a call admission policy for new call requests to maintain acceptable connections for existing users. In this work, we use a weighted combination of call blocking and call dropping probabilities as a system performance measure. We study a transmitted power based call admission control (TPCAC) scheme that protects ongoing calls and a received power based call admission control (RPCAC) scheme that blocks new calls when the total received at a base station exceeds a threshold. The proposed schemes are evaluated by simulation of a one dimensional system and the RPCAC scheme is found to offer significant performance improvements.

I. INTRODUCTION

In power controlled CDMA systems, transmitted power is regulated to provide each user an acceptable connection by limiting interference caused by other users. In these systems, the number of users that each cell can support is limited by the total interference received at each base station and will vary with time. When a system is congested, admitting a new call can only make link quality worse for ongoing calls and may lead to call dropping. Thus, a system needs a call admission policy for new call requests to maintain acceptable connections for existing users.

In a wireless cellular network, state based call admission policies have been examined under a variety of assumptions [1]–[3]. However, for a CDMA system, the continuous state space describes users' positions and transmitter powers makes state based admission control algorithms intractable. In [4], [5], a power control method to maintain the active links above their required quality while new users are been admitted or blocked is considered. In [6], [7], carrier to interference ratio (CIR) thresholds are used for call admission control. In these works, call admission is based on available capacity and attempts to protect existing users. In [8], an admission control based on the outage probability associated with a target CIR is examined. That algorithm needs to calculate the eigenvector of the normalized gain matrix to see whether there exists a feasible solution. In [9], the admission control is formulated as an optimization problem with the objective being to provide acceptable service to as many mobiles as possible. In [10], a soft admission control is used to protect existing users in orthogonal channel systems.

In this work, we consider two simple call admission schemes. In the Transmitter Power Call Admission Control (TPCAC) scheme, we block a new call when that new call causes ongoing calls to transmit at maximum power. Essentially, TPCAC admits a call if all ongoing calls can maintain acceptable CIR. In the Received Power Call Admission Control (RPCAC) scheme, we block new calls at a base station when the total received power measured at that base station exceeds a threshold.

II. SYSTEM MODEL

We assume N users and M base stations and a common radio channel. Let p_i denote the transmitted power of user i so that $p = [p_1, ..., p_N]^T$ denotes the power vector of the system. The corresponding received signal power of user i at base k is $h_{ki}p_i$ where h_{ki} denotes the gain for user i to base k. The interference seen by user i at base k is $\sum_{j \neq i} h_{kj}p_j$. A CIR requirement of γ_i for user i at base station k can be expressed as

$$\frac{h_{ki}p_i}{\sum_{j \neq i} h_{kj}p_j + \eta_k} \geq \gamma_i \qquad (1)$$

where η_k describes the receiver noise at base station k. When user i is assigned to base k, we can write the CIR constraint for user i as

$$p_i \geq H_i^{(k)}p + \delta_i^{(k)} \qquad (2)$$

where $\delta_i^{(k)} = \gamma_i \eta_k / h_{ki}$ and $H_i^{(k)}$ is a normalized row vector with jth element

$$H_{ij}^{(k)} = \begin{cases} \gamma_i \dfrac{h_{kj}}{h_{ki}} & j \neq i \\ 0 & j = i \end{cases} \qquad (3)$$

In CDMA systems, the base station assignment is closely tied to the power control. In this work, we consider three approaches:

Fixed Assignment (FA): [11]–[16] Each mobile i has an assigned base a_i which we assume to be fixed and specified by pilot signal strength. From Equation (3), the power control iteration of user i at its assigned base a_i can be written

$$p_i(n + 1) = \min\left\{ H_i^{(a_i)}p(n) + \delta_i^{(a_i)}, q_i \right\} \qquad (4)$$

Under FA, the base station is chosen by pilot signal strength and is independent of CIR measures but the power control is based on CIR measures.

IS-95: [17] In this case, power control and base station assignment is based on the best received signal quality among a set of active bases. The set of active base stations for user i is

$$B_i^{soft} = \{k | T_i^{(k)} \geq T_{ADD}\} \qquad (5)$$

where $T_i^{(k)}$ is the ratio of the received pilot signal from base station k to total received power measured by user i and T_{ADD} is the threshold value. When B_i^{soft} contains more than one base station, we say user i is in soft handoff. The power adjustment for user i can be written

$$p_i(n+1) = \min \left\{ \min_{k \in B_i^{soft}} H_i^{(k)} p(n) + \delta_i^{(k)}, q_i \right\} \qquad (6)$$

Constrained Minimum Power Assignment (CMPA): [18]–[20] At each step of the CMPA algorithm, user i is assigned to the base station k at which its required transmitter power is minimized. The power adjustment of user i can be written

$$p_i(n+1) = \min \left\{ \min_k H_i^{(k)} p(n) + \delta_i^{(k)}, q_i \right\} \qquad (7)$$

Under CMPA, user i is always assigned to the base station at which its CIR is highest. One can view the CMPA algorithm as a system in which all mobiles are always in soft handoff with all base stations.

In [21], it is verified that for each of these systems with maximum power constraints, the iterative power control algorithm is guaranteed to converge to a unique fixed point at which infeasibility can be detected. In particular, at the fixed point, a user that cannot meet its CIR requirement is transmitting at maximum power.

III. CDMA Cell Load Measurement

Since the capacity at each base station is shared by all users, a meaningful cell load measure should also include the interference caused by users assigned to adjacent cells. We show that cell load can be measured by total received power at the base station.

We assume that each user i has an identical CIR requirement $\gamma_i = \gamma$. When the power control algorithm has converged to a feasible solution, all users assigned to base station k will have equal received power R_k and corresponding CIR

$$\gamma = \frac{R_k}{(N_k - 1)R_k + I_k + \eta_k} \qquad (8)$$

where at base k, N_k is the number of users assigned, η_k is the receiver noise, and I_k is the external interference that depends not only on the system load but also on the spatial distribution of mobile users.

In CDMA systems, the maximum capacity for a cell is achieved when there is no interference except from users assigned to that cell. That is $I_k = \eta_k = 0$. From Equation (8), the number of users assigned to base station k must satisfy $N_k \leq 1 + 1/\gamma$. Thus, the maximum capacity for base station k is

$$N_{max} = 1/\gamma + 1 \qquad (9)$$

We now characterize the capacity at cell k in terms of the received power requirement R_k. Let $L_k = I_k/R_k$ denote an effective number of cell k users caused by external interference. That is, we model the external interference I_k by an equivalent number of base k users. Substituting $L_k R_k$ for I_k in Equation (8) yields

$$R_k = \frac{\eta_k}{1/\gamma + 1 - N_k - L_k} \qquad (10)$$

Cell load is traditionally defined as the ratio of the number of users assigned to a cell and the maximum capacity of that cell. However, in CDMA systems, we know the number of users that each base station can support is not fixed and depends strongly on the load of the adjacent cell. In order to calculate a meaningful cell load, we need to take the effect of external interference into account. So, we have the cell load of base station k, X_k, is

$$X_k = \frac{N_k + L_k}{N_{max}} = \frac{N_k + L_k}{1/\gamma + 1} \qquad (11)$$

From Equation (10), It is easy to show that X_k, is the ratio of the sum of all active users' received powers to the total received power. That is,

$$X_k = \frac{N_k R_k + I_k}{N_k R_k + I_k + \eta_k} = \frac{Z_k - \eta_k}{Z_k} \qquad (12)$$

where $Z_k = N_k R_k + I_k + \eta_k$ denotes the total received power at base station k. Since $Z_k = \eta_k/(1 - X_k)$, total received power Z_k can be used to measure cell load. Note that when the power control problem has no feasible solution and transmitter powers are unconstrained, all powers will increase without bound. In this case, the total received power Z_k diverges while the cell load X_k approaches 1.

The maximum transmitter power should be chosen such that users can have sufficient transmitter power to achieve their quality requirements when the system reaches the allowable system load. Traditionally in system planning, the available transmitter power budget and the channel environment to determine the coverage area. Here, on the contrary, we want to find out the required maximum transmitter power, p_{max}, when we know the background noise, coverage area and propagation model.

From (12), we have

$$1 - X_k = \frac{\eta_k}{Z_k} = \frac{\eta_k}{\sum_j p_j h_{kj} + \eta_k} \qquad (13)$$

We know that the CIR of user i at the base station k is

$$\frac{p_i h_{ki}}{\sum_j p_j h_{kj} - p_i h_{ki} + \eta_k} = \gamma \qquad (14)$$

From Equation (13) and Equation (14), we have the required transmitted power of user i at base station k

$$p_i = \frac{\gamma}{1+\gamma} \frac{\eta_k}{h_{ki}(1-X_k)} \qquad (15)$$

For fixed γ and η_k, the required transmitted power depends on the cell load and the gain between the user and the base station. For fixed gain h_{ki} the required power grows rapidly when the cell load exceeds 90%.

IV. CALL ADMISSION STRATEGIES

To describe TPCAC, we assume there is a call setup phase consisting of N power control iterations. In this set up phase, a new user i as well as existing users participate in the power control algorithm yielding a power vector $p(n)$ after n iterations. We define a decision set $D(n)$ that consists of a subset of mobiles whose transmitter powers will be used to decide if the new call is blocked at the nth iteration. We will consider two candidates for the decision set $D(n)$. First, we let $D(n) = \{i\}$. That is, we examine only the transmitted power of the new user i. Second, we let $D(n) = U_i$, the set of mobiles that are assigned to the same base as the new mobile i after iteration n.

Algorithm 1 TPCAC. *For $1 \le n \le N$, block the new call at step n if $p_i(n) \ge q_i$ for any $i \in D(n)$; otherwise admit the call after N iterations.*

Since new calls participate in the iterative power control before a decision is made, TPCAC is a form of interactive admission control [10]. There is a tradeoff in the choice of N. With large N, the system is more likely to correctly identify whether the call can be admitted but the set up phase will last longer which will increase implementation complexity.

By contrast, our second method, RPCAC, is a simple non-interactive admission scheme. In RPCAC, the new user will be accepted at base k as long as the total received power Z_k at base k is less than a predefined threshold value Z_k^*.

Algorithm 2 RPCAC. *Admit at base station k iff $Z_k(p) \le Z_k^*$.*

The approach of RPCAC is to predict cell congestion by total received power and to reserve capacity at each base station for handoff traffic.

V. SIMULATION RESULTS

We examine by simulation the performance of the proposed call admission control algorithm on a system of ten base stations uniformly spaced every 2000 meters on a ring. For each base station, the uplink gain included an order $\alpha = 4$ propagation loss and a position dependent log normal shadow fading component. That is, expressed in dB, the uplink gain h_{ki} of user i to base k at a distance d_{ki} is

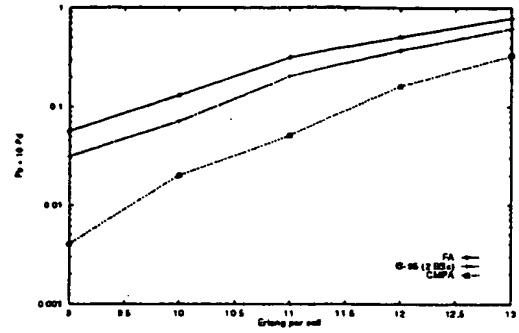$$10 \log h_{ki} = -10\alpha \log d_{ki} + S_k(d_{ki}) \qquad (16)$$
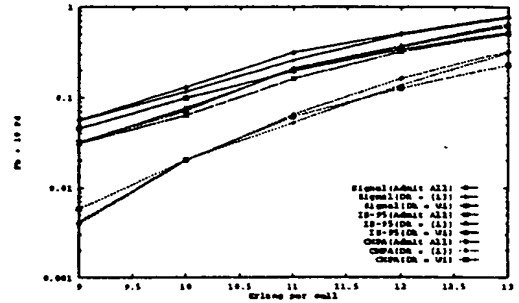

Fig. 1. Admit All Policy: FA, IS-95 (2 BSs), and CMPA
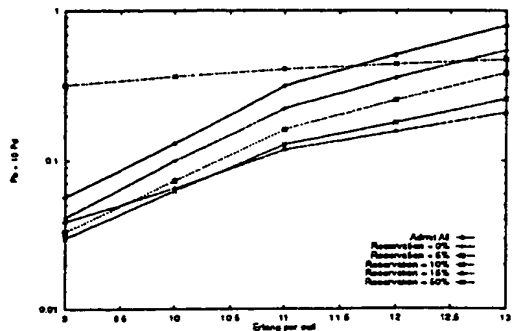

Fig. 2. TPCAC: FA, IS-95 (with 2 BSs) and CMPA
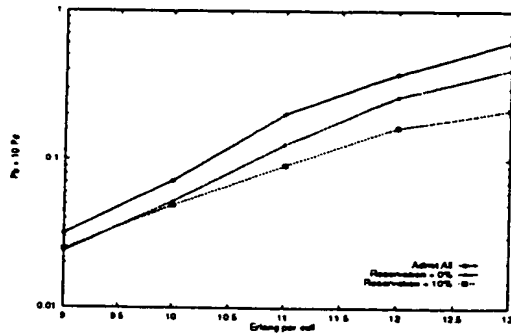

Fig. 3. RPCAC: Fixed Assignment

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Fig. 4. RPCAC: IS-95 with 2 BSs (always consider two base station for reassignment)
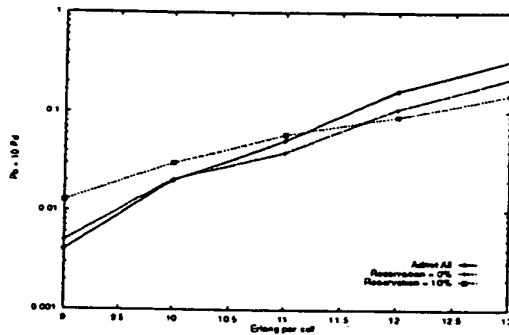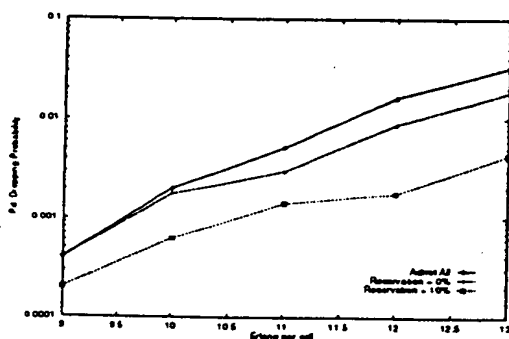

Fig. 5. RPCAC: CMPA Algorithm

Fig. 6. RPCAC – Dropping Probability: CMPA Algorithm

The shadow fading component $S_k(d_{k,i})$ was taken to be a normal random variable with mean 0 and standard deviation $\eta = 8$ dB. The shadow fading processes $S_k(d)$ and $S_{k'}(d')$ for distinct base stations k and k' were assumed to be independent. The correlation over distance of the shadow fading was described by the autocorrelation function

$$\rho(d) = E[S_j(d')S_j(d' + d)] = \eta^2 e^{-|d|/d_0} \qquad (17)$$

with a correlation distance of $d_0 = 4.5$ meters. Each mobile aimed for a CIR target of $\gamma = 1/20$ that reflected the processing gain associated with a CDMA system. We examine the performance of different power control algorithms in a simulation of mobile users arriving and departing on the ring of base stations. In this case, call blocking and call dropping that results from user mobility define the system performance.

We assume that new calls (users) arrive as an independent Poisson process. Each call is randomly started on the ring. Call holding times are independent and exponentially distributed with a mean time of 120 seconds. A mobile's speed follows a truncated Gaussian distribution with mean speed of 90 km/hr, minimum speed of 60 km/hr and maximum speed of 120 km/hr. The "clockwise" and "counterclockwise" directions are equally likely. The velocity of a terminal remains fixed throughout duration of a call. By varying the call arrival rate, we consider offered traffic loads ranging from 9 to 13 Erlangs per base station.

In particular, we wish to identify whether the proposed call admission control can effectively improve the system performance. Let P_b and P_d denote the fraction of mobile calls that are blocked and dropped respectively during a simulation. We define a cost function, $10P_d + P_b$ in which we assume that dropping a call is 10 times worse than blocking a new call. Blocking of new call attempts occurs when either the required transmitted power of the new call exceeds the maximum power or when the admission control scheme chooses to block. No new call will be blocked when admit all scheme is chosen. Call dropping occurs if at any time a user has CIR 3 dB lower than the target CIR.

In this study, the allowable cell load is 0.9. That is, the maximum transmitter power is chosen such that when the load in cell k is $X_k = 0.9$, a user at the boundary of the cell is transmitting at maximum power (in the absence of shadow fading). When a base station's cell load exceeds 0.9, users assigned to the base station can not maintain the target CIR at boundary. The system performance depends on the power control/base station assignment algorithms. As shown in Figure 1, the CMPA has the best results when no admission control is used

For fixed assignment, as shown in Figure 2, the TP-CAC does not measurably improve system performance for $D_k = \{i\}$. Especially, at low traffic load, there is no improvement by simply checking the required transmitted power of the new user i. This is because the required transmitted power not only depends on system congestion level but also depends on the gain between user and the con-

nected base station. The trans⬤d power of just the new user does not necessarily reflect the system congestion or the connection problems of other on going users.

For $D(n) = U_i$, performance under fixed assignment is slightly improved. However, the improvement is essentially zero when the system implements better power control/base assignment schemes such as the IS-95 or CMPA schemes. As shown in Figure 2, the IS-95 based and the CMPA based power control shames can support higher traffic load than the fixed assignment strategy, but TPCAC offers less or no improvement in system performance.

Now we examine the the proposed RPCAC scheme. In the RPCAC, the reservation is done by lowering the allowable cell load, compared to $X_k = 0.9$, for call admission control. From Figures 3 through 5. it is clear that RPCAC can significantly improve system performance, especially at higher load. This conclusion holds for fixed assignment, IS-95 assignment, as well as the CMPA assignment. When the traffic load decreases, the extent of the improvement is reduced. This appears to occur because when system is less congested, the reservation causes unnecessary call blocking which will degrade system performance. The improvement in performance typically increases (even at low traffic load) until the capacity is reserved more than 10%. With the cost of increasing blocking probability, higher (15% or above) reservation is less desirable.

We conclude that the total received power provides a more useful measure of system load than users' transmitter powers of individual users. In particular, the RPCAC algorithm provided significant reductions in the weighted combination of call blocking and call dropping. We believe that the proposed call admission control scheme can be further extended to a system which considers to provide multimedia services. Due to the heterogeneous requirements, call admission control can be more effective in improving system performance [22].

REFERENCES

[1] S. Jordan and A. Khan. A Performance Bound on Dynamic Channel Allocation in Cellular Systems: Equal Load . *IEEE Trans. Veh. Technol.*, 43(2):333–344, May 1994.

[2] M. Saquib and R.D. Yates. Optimal call admission to mobile cellular networks. In *Proc. IEEE Vehicular Technology Conference, VTC-95*, 1995.

[3] A. Yener and C. Rose. Near-optimal call admission policies for cellular networks using genetic algorithm. In *The Sixth International Conference on Wireless Communications*, pages 398–410, July 1994.

[4] S. Chen, N. Bambos, and G. Pottie. On power control with active link quality protection in wireless communication networks. In *Proc. 28th Annual Conference on Information Sciences and Systems, Princeton University, Princeton, NJ*, 1994.

[5] N. Bambos, S. Chen, and G. Pottie. Radio link admission algorithms for wireless networks with power control and active link quality protection. UCLA-TR UCLA-ENG-94-25, UCLA, 1994.

[6] Z. Liu and M.E. Zarki. SIR based call admission control for DS-CDMA cellular systems. *IEEE Journal on Selected Areas in Communication*, 12(4), May 1994.

[7] C.N. Chuah, R. Yates, and D. Goodman. Integrated dynamic radio resource managemant. In *Proc. IEEE Vehicular Technology Conference, VTC-95*, 1995.

[8] J. Zander. Tr⬤tter power control for co-channel interference management in cellular radio systems. In *Fourth WIN-LAB Workshop on Third Generation Wireless Information Networks*, 1993.

[9] N. Bambos and G. Pottie. Power control based admission policies in cellular radio networks. In *IEEE Global Telecommunications Conference, GLOBECOM-92*, 1992.

[10] M. Andersin, Z. Rosberg, and J. Zander. Soft admission in cellular PCS with constrained power control and noise. In *Fifth WINLAB Workshop on Third Generation Wireless Information Networks*, 1995.

[11] J. M. Aein. Power balancing in system employing frequency reuse. *COMSAT Technical Review*, 3(2), Fall 1973.

[12] R. W. Nettleton and H. Alavi. Power control for spread-spectrum cellular mobile radio system. In *Proc. IEEE Vehicular Technology Conference, VTC-83*, 1983.

[13] S. Grandhi, R. Vijayan, D. J. Goodman, and J. Zander. Centralized power control for cellular radio systems. *IEEE Transactions on Vehicular Technology*, 42(4), November 1993.

[14] J. Zander. Performance of optimum transmitter power control in cellular radio systems. *IEEE Transactions on Vehicular Technology*, 41, February 1992.

[15] G.J. Foschini and Z. Miljanic. A simple distributed autonomous power control algorithm and its convergence. *IEEE Transactions on Vehicular Technology*, 42(4), November 1993.

[16] S. Chen, N. Bambos, and G. Pottie. On distributed power control for radio networks. In *IEEE International Conference on Communications, ICC-94*, pages 1281–1285, 1994.

[17] EIA/TIA/IS-95 mobile station-base station compatibility standard for dual-mode wideband spread spectrum cellular system, July 1993.

[18] R. Yates and C.Y. Huang. Constrained power control and base station assignment in cellular radio systems. *IEEE/ACM Transactions on Networking*, 1995. to appear.

[19] R. Yates and C.Y. Huang. Integrated power control and base station assignment. *IEEE Transactions on Vehicular Technology*, August 1995.

[20] S. V. Hanly. An algorithm for combined cell-site selection and power control to maximize cellular spread spectrum capacity. *IEEE Journal on Selected Areas in Communications*, 13(7):1332–1340, September 1995.

[21] R. Yates. A framework for uplink power control in cellular radio systems. *IEEE Journal on Selected Areas in Communications*, 13(7):1341–1347, September 1995.

[22] C.M. Barnhart and A. Ephremides. An approach to voice admission control in multihop wireless networks. In *Proc. IEEE Vehicular Technology Conference, VTC-93*, 1993.

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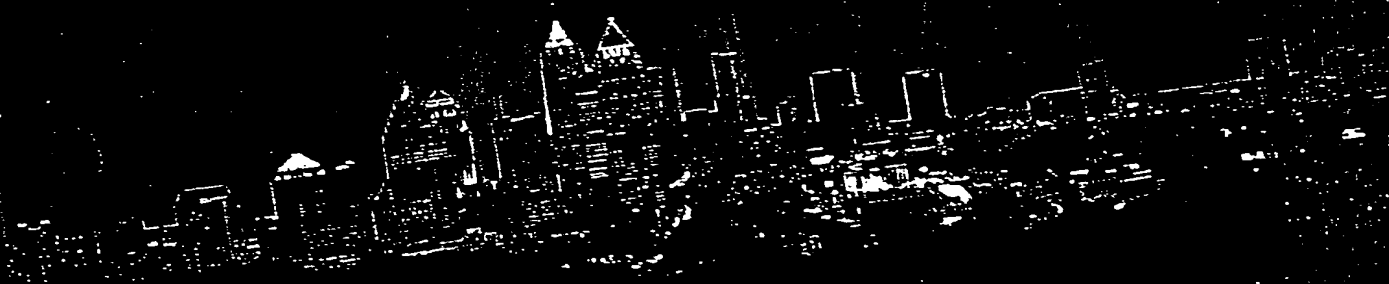
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